Shea, Valois

From: Ex. 6 Personal Privacy (PP)
Sent: Tuesday, May 23, 2017 11:30 PM
To: Shea, Valois
Subject: comments on Dewey-Burdock permit application

Comments on Dewey-Burdock ISM Disposal Well Permit Application

The permit application fails to address the reasonably foreseeable event of a natural or induced earthquake along the Dewey fault, which lies only a mile from the project area. The geologic study prepared for the permit application does not employ best current science. To be specific:

1. The study does not classify the Dewey fault as a capable fault. As nearly as I can determine, the Dewey fault meets at two of the four criteria for a capable fault, only one of which is needed for a fault to be classified as capable. It may meet all four criteria; however, this is difficult to determine because local seismic data are not available to me.

(Definition of capable fault can be found here:

https://www.nrc.gov/reading-rm/doc-collections/cfr/part100/part100-appa.html

Earthquakes of greater than 3.0 magnitude have occurred in the immediate area on July 17, 1920, December 30, 1924, and May 3, 1996. A 3.5 magnitude earthquake east of the town of Custer that occurred on December 12, 2013, may have been associated with the Dewey fault.

Please explain how it was determined that the Dewey fault is not capable.

2. The permit application assumes that movement along the Dewey fault, which is already estimated as having experienced a 440-foot vertical displacement, cannot disrupt "confining" shale strata that are only 20 to 80 feet thick. This assumption is clearly wrong. Nowhere does the permit application address this scenario.

Source: https://www.nps.gov/parkhistory/online_books/geology/publications/bul/1063-G/sec2.htm

What is the basis for the assumption that the movement of the Dewey fault will not cause displacement of the so-called confining strata and mixing of aquifers?

3. The application does not address the possibility of induced earthquakes from the waste-disposal wells needed in the proposed uranium extraction process, nor does it address the likelihood of eventual hydraulic fracturing to extract oil and gas in western Fall River County. According to USGS studies, deep wells used to dispose of wastewater from fracking can cause earthquakes as far as 10 miles from the location of an injection well: "Earthquakes can be induced at distances of 10 miles or more away from the injection point and at significantly greater depths than the injection point." Note that the Dewey Fault is only two miles from the proposed well sites. (USGS website, accessed 5/22/2017.)

http://rapidcityjournal.com/news/local/seismic-crews-want-to-test-up-to-acres-northwest-of/article_2d670e86-f90b-5db4-8bd6-19075034e04e.html

What is the reason for assuming that neither natural nor induced earthquakes can happen in or near the project area and create disruption of confining strata and mixing of underground water bodies?

4. Further, the USGS studies demonstrate that injection wells can cause such earthquakes even without the presence of high-pressure injection. "In operations where engineers pour fluid down the well without added pressure at the wellhead still increase the fluid pressure within the formation and thus can induce earthquakes." (USGS website, accessed 5/22/2017.)

Please explain why it is assumed here that the proposed wells cannot induce earthquakes, given the presence of relatively soft rock strata and geologic faults within and adjacent to the project area.

5. The USGS has developed methods to estimate the risk of such wells causing earthquakes. These methods have not been applied here. (USGS website, accessed 5/22/2017.)

Please clarify whether earthquake risk evaluation methods have been applied here and state the results of such evaluations.

6. The permit application does not incorporate recent studies showing that water moves between aquifers to a much greater degree than previously thought.

http://www.nature.com/ngeo/journal/vaop/ncurrent/full/ngeo2943.html

The permit application assumes that the relatively thin "confining" strata do not allow mixing of water from the various permeable strata. Please re-evaluate in light of this new research or explain why such analysis is not needed here.

7. I also notice that the permit application makes no mention of a fault lying within the project area, which is described in *Stratigraphic and Structural Controls of Uranium Deposits on Long Mountain, South Dakota*, by William A. Braddock, US Geological Survey Bulletin 1063-A, 1957, page 51.

Why was the presence of this fault omitted from the application?

8. Regarding the surface-application alternative. The proposal is to fence the area where contaminated water will be applied to keep out livestock and people. How will you assure that deer and pronghorn do not enter this area and consume grass with high levels of arsenic and radioactive elements, which can then enter the human food chain via hunting and consumption of these animals?

Ex. 6 Personal Privacy (PP)

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Appendix A to Part 100—Seismic and Geologic Siting Criteria for Nuclear Power Plants

I. Purpose

General Design Criterion 2 of Appendix A to part 50 of this chapter requires that nuclear power plant structures, systems, and components important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. It is the purpose of these criteria to set forth the principal seismic and geologic considerations which guide the Commission in its evaluation of the suitability of proposed sites for nuclear power plants and the suitability of the plant design bases established in consideration of the seismic and geologic characteristics of the proposed sites.

These criteria are based on the limited geophysical and geological information available to date concerning faults and earthquake occurrence and effect. They will be revised as necessary when more complete information becomes available.

II. Scope

These criteria, which apply to nuclear power plants, describe the nature of the investigations required to obtain the geologic and seismic data necessary to determine site suitability and provide reasonable assurance that a nuclear power plant can be constructed and operated at a proposed site without undue risk to the health and safety of the public. They describe procedures for determining the quantitative vibratory ground motion design basis at a site due to earthquakes and describe information needed to determine whether and to what extent a nuclear power plant need be designed to withstand the effects of surface faulting. Other geologic and seismic factors required to be taken into account in the siting and design of nuclear power plants are identified.

The investigations described in this appendix are within the scope of investigations permitted by § 50.10(a)(2)(ii) of this chapter.

Each applicant for a construction permit shall investigate all seismic and geologic factors that may affect the design and operation of the proposed nuclear power plant irrespective of whether such factors are explicitly included in these criteria. Additional investigations and/or more conservative determinations than those included in these criteria may be required for sites located in areas having complex geology or in areas of high seismicity. If an applicant believes that the particular seismology and geology of a site indicate that some of these criteria, or portions thereof, need not be satisfied, the specific sections of these criteria should be identified in the license application, and supporting data to justify clearly such departures should be presented.

These criteria do not address investigations of volcanic phenomena required for sites located in areas of volcanic activity. Investigations of the volcanic aspects of such sites will be determined on a case-by-case basis.

III. Definitions

As used in these criteria:

(a) The *magnitude* of an earthquake is a measure of the size of an earthquake and is related to the energy released in the form of seismic waves. *Magnitude* means the numerical value on a Richter scale.

(b) The *intensity* of an earthquake is a measure of its effects on man, on man-built structures, and on the earth's surface at a particular location. Intensity means the numerical value on the Modified Mercalli scale.

(c) The *Safe Shutdown Earthquake*[1] is that earthquake which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to assure:

(1) The integrity of the reactor coolant pressure boundary,

(2) The capability to shut down the reactor and maintain it in a safe shutdown condition, or

(3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the guideline exposures of this part.

(d) The *Operating Basis Earthquake* is that earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant; it is that earthquake which produces the vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

(e) A *fault* is a tectonic structure along which differential slippage of the adjacent earth materials has occurred parallel to the fracture plane. It is distinct from other types of ground disruptions such as landslides, fissures, and craters. A fault may have gouge or breccia between its two walls and includes any associated monoclinal flexure or other similar geologic structural feature.

(f) *Surface faulting* is differential ground displacement at or near the surface caused directly by fault movement and is distinct from nontectonic types of ground disruptions, such as landslides, fissures, and craters.

(g) A *capable fault* is a fault which has exhibited one or more of the following characteristics:

(1) Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.

(2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.

(3) A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph such that movement on one could be reasonably expected to be accompanied by movement on the other.

In some cases, the geologic evidence of past activity at or near the ground surface along a particular fault may be obscured at a particular site. This might occur, for example, at a site having a deep overburden. For these cases, evidence may exist elsewhere along the fault from which an evaluation of its characteristics in the vicinity of the site can be reasonably based. Such evidence shall be used in determining whether the fault is a capable fault within this definition.

Notwithstanding the foregoing paragraphs III(g) (1), (2) and (3), structural association of a fault with geologic structural features which are geologically old (at least pre-Quaternary) such as many of those found in the Eastern region of the United States shall, in the absence of conflicting evidence, demonstrate that the fault is not a capable fault within this definition.

(h) A *tectonic province* is a region of the North American continent characterized by a relative consistency of the geologic structural features contained therein.

(i) A *tectonic structure* is a large scale dislocation or distortion within the earth's crust. Its extent is measured in miles.

(j) A *zone requiring detailed faulting investigation* is a zone within which a nuclear power reactor may not be located unless a detailed investigation of the regional and local geologic and seismic characteristics of the site demonstrates that the need to design for surface faulting has been properly determined.

(k) The *control width* of a fault is the maximum width of the zone containing mapped fault traces, including all faults which can be reasonably inferred to have experienced differential movement during Quaternary times and which join or can reasonably be inferred to join the main fault trace, measured within 10 miles along the fault's trend in both directions from the point of nearest approach to the site. (See Figure 1 of this appendix.)

(l) A *response spectrum* is a plot of the maximum responses (acceleration, velocity or displacement) of a family of idealized single-degree-of-freedom damped oscillators against natural frequencies (or periods) of the oscillators to a specified vibratory motion input at their supports.

IV. Required Investigations

The geologic, seismic and engineering characteristics of a site and its environs shall be investigated in sufficient scope and detail to provide reasonable assurance that they are sufficiently well understood to permit an adequate evaluation of the proposed site, and to provide sufficient information to support the determinations required by these criteria and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site. The size of the region to be investigated and the type of data pertinent to the investigations shall be determined by the nature of the region surrounding the proposed site. The investigations shall be carried out by a review of the pertinent literature and field investigations and shall include the steps outlined in paragraphs (a) through (c) of this section.

(a) *Required Investigation for Vibratory Ground Motion.* The purpose of the investigations required by this paragraph is to obtain information needed to describe the vibratory ground motion produced by the Safe Shutdown Earthquake. All of the steps in paragraphs (a)(5) through (a)(8) of this section need not be carried out if the Safe Shutdown Earthquake can be clearly established by investigations and determinations of a lesser scope. The investigations required by this paragraph provide an adequate basis for selection of an Operating Basis Earthquake. The investigations shall include the following:

(1) Determination of the lithologic, stratigraphic, hydrologic, and structural geologic conditions of the site and the region surrounding the site, including its geologic history;

(2) Identification and evaluation of tectonic structures underlying the site and the region surrounding the site, whether buried or expressed at the surface. The evaluation should consider the possible effects caused by man's activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams or reservoirs;

(3) Evaluation of physical evidence concerning the behavior during prior earthquakes of the surficial geologic materials and the substrata underlying the site from the lithologic, stratigraphic, and structural geologic studies;

(4) Determination of the static and dynamic engineering properties of the materials underlying the site. Included should be properties needed to determine the behavior of the underlying material during earthquakes and the characteristics of the underlying material in transmitting earthquake-induced motions to the foundations of the plant, such as seismic wave velocities, density, water content, porosity, and strength;

(5) Listing of all historically reported earthquakes which have affected or which could reasonably be expected to have affected the site, including the date of occurrence and the following measured or estimated data: magnitude or highest intensity, and a plot of the epicenter or location of highest intensity. Where historically reported

earthquakes could have caused a maximum ground acceleration of at least one-tenth the acceleration of gravity (0.1g) at the foundations of the proposed nuclear power plant structures, the acceleration or intensity and duration of ground shaking at these foundations shall also be estimated. Since earthquakes have been reported in terms of various parameters such as magnitude, intensity at a given location, and effect on ground, structures, and people at a specific location, some of these data may have to be estimated by use of appropriate empirical relationships. The comparative characteristics of the material underlying the epicentral location or region of highest intensity and of the material underlying the site in transmitting earthquake vibratory motion shall be considered;

(6) Correlation of epicenters or locations of highest intensity of historically reported earthquakes, where possible, with tectonic structures any part of which is located within 200 miles of the site. Epicenters or locations of highest intensity which cannot be reasonably correlated with tectonic structures shall be identified with tectonic provinces any part of which is located within 200 miles of the site;

(7) For faults, any part of which is within 200 miles[2] of the site and which may be of significance in establishing the Safe Shutdown Earthquake, determination of whether these faults are to be considered as capable faults.[3],[4] This determination is required in order to permit appropriate consideration of the geologic history of such faults in establishing the Safe Shutdown Earthquake. For guidance in determining which faults may be of significance in determining the Safe Shutdown Earthquake, table 1 of this appendix presents the minimum length of fault to be considered versus distance from site. Capable faults of lesser length than those indicated in table 1 and faults which are not capable faults need not be considered in determining the Safe Shutdown Earthquake, except where unusual circumstances indicate such consideration is appropriate;

Table 1

Distance from the site (miles):	**Minimum length**[1]
0 to 20	1
Greater than 20 to 50	5
Greater than 50 to 100	10
Greater than 100 to 150	20
Greater than 150 to 200	40

[1] Minimum length of fault (miles) which shall be considered in establishing Safe Shutdown Earthquake.

(8) For capable faults, any part of which is within 200 miles[2] of the site and which may be of significance in establishing the Safe Shutdown Earthquake, determination of:

(i) The length of the fault;

(ii) The relationship of the fault to regional tectonic structures; and

(iii) The nature, amount, and geologic history of displacements along the fault, including particularly the estimated amount of the maximum Quaternary displacement related to any one earthquake along the fault.

(b) *Required Investigation for Surface Faulting*. The purpose of the investigations required by this paragraph is to obtain information to determine whether and to what extent the nuclear power plant need be designed for surface faulting. If the design basis for surface faulting can be clearly established by investigations of a lesser scope, not all of the steps in paragraphs (b)(4) through (b)(7) of this section need be carried out. The investigations shall include the following:

(1) Determination of the lithologic, stratigraphic, hydrologic, and structural geologic conditions of the site and the area surrounding the site, including its geologic history;

(2) Evaluation of tectonic structures underlying the site, whether buried or expressed at the surface, with regard to their potential for causing surface displacement at or near the site. The evaluation shall consider the possible effects caused by man's activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams or reservoirs;

(3) Determination of geologic evidence of fault offset at or near the ground surface at or near the site;

(4) For faults greater than 1000 feet long, any part of which is within 5 miles[5] of the site, determination of whether these faults are to be considered as capable faults;[6],[7]

(5) Listing of all historically reported earthquakes which can reasonably be associated with capable faults greater than 1000 feet long, any part of which is within 5 miles[5] of the site, including the date of occurrence and the following measured or estimated data: magnitude or highest intensity, and a plot of the epicenter or region of highest intensity;

(6) Correlation of epicenters or locations of highest intensity of historically reported earthquakes with capable faults greater than 1000 feet long, any part of which is located within 5 miles[5] of the site;

(7) For capable faults greater than 1000 feet long, any part of which is within 5 miles[5] of the site, determination of:

(i) The length of the fault;

(ii) The relationship of the fault to regional tectonic structures;

(iii) The nature, amount, and geologic history of displacements along the fault, including particularly the estimated amount of the maximum Quaternary displacement related to any one earthquake along the fault; and

(iv) The outer limits of the fault established by mapping Quaternary fault traces for 10 miles along its trend in both directions from the point of its nearest approach to the site.

(c) *Required Investigation for Seismically Induced Floods and Water Waves*. (1) For coastal sites, the investigations shall include the determination of:

(i) Information regarding distantly and locally generated waves or tsunami which have affected or could have affected the site. Available evidence regarding the runup and drawdown associated with historic tsunami in the same coastal region as the site shall also be included;

(ii) Local features of coastal topography which might tend to modify tsunami runup or drawdown. Appropriate available evidence regarding historic local modifications in tsunami runup or drawndown at coastal locations having topography similar to that of the site shall also be obtained; and

(iii) Appropriate geologic and seismic evidence to provide information for establishing the design basis for seismically induced floods or water waves from a local offshore earthquake, from local offshore effects of an onshore earthquake, or from coastal subsidence. This evidence shall be determined, to the extent practical, by a procedure similar to that required in paragraphs (a) and (b) of this section. The probable slip characteristics of offshore faults shall also be considered as well as the potential for offshore slides in submarine material.

(2) For sites located near lakes and rivers, investigations similar to those required in paragraph (c)(1) of this section shall be carried out, as appropriate, to determine the potential for the nuclear power plant to be exposed to seismically induced floods and water waves as, for example, from the failure during an earthquake of an upstream dam or from slides of earth or debris into a nearby lake.

V. Seismic and Geologic Design Bases

(a) *Determination of Design Basis for Vibratory Ground Motion*. The design of each nuclear power plant shall take into account the potential effects of vibratory ground motion caused by earthquakes. The design basis for the maximum vibratory ground motion and the expected vibratory ground motion should be determined through evaluation of the seismology, geology, and the seismic and geologic history of the site and the surrounding region. The most severe earthquakes associated with tectonic structures or tectonic provinces in the region surrounding the site should be identified, considering those historically reported earthquakes that can be associated with these structures or provinces and other relevant factors. If faults in the region surrounding the site are capable faults, the most severe earthquakes associated with these faults should be determined by also considering their geologic history. The vibratory ground motion at the site should be then determined by assuming that the epicenters or locations of highest intensity of the earthquakes are situated at the point on the tectonic structures or tectonic provinces nearest to the site. The earthquake which could cause the maximum vibratory ground motion at the site should be designated the Safe Shutdown Earthquake. The specific procedures for determining the design basis for vibratory ground motion are given in the following paragraphs.

(1) *Determination of Safe Shutdown Earthquake*. The Safe Shutdown Earthquake shall be identified through evaluation of seismic and geologic information developed pursuant to the requirements of paragraph IV(a), as follows:

(i) The historic earthquakes of greatest magnitude or intensity which have been correlated with tectonic structures pursuant to the requirements of paragraph (a)(6) of section IV shall be determined. In addition, for capable faults, the information required by paragraph (a)(8) of section IV shall also be taken into account in determining the earthquakes of greatest magnitude related to the faults. The magnitude or intensity of earthquakes based on geologic evidence may be larger than that of the maximum earthquakes historically recorded. The accelerations at the site shall be determined assuming that the epicenters of the earthquakes of greatest magnitude or the locations of highest intensity related to the tectonic structures are situated at the point on the structures closest to the site;

(ii) Where epicenters or locations of highest intensity of historically reported earthquakes cannot be reasonably related to tectonic structures but are identified pursuant to the requirements of paragraph (a)(6) of section IV with tectonic provinces in which the site is located, the accelerations at the site shall be determined assuming that these earthquakes occur at the site;

(iii) Where epicenters or locations of the highest intensity of historically reported earthquakes cannot be reasonably related to tectonic structures but are identified pursuant to the requirements of paragraph (a)(6) of section IV with tectonic provinces in which the site is not located, the accelerations at the site shall be determined assuming that the epicenters or locations of highest intensity of these earthquakes are at the closest point to the site on the boundary of the tectonic province;

(iv) The earthquake producing the maximum vibratory acceleration at the site, as determined from paragraph (a)(1)(i) through (iii) of this section shall be designated the Safe Shutdown Earthquake for vibratory ground motion, except as noted in paragraph (a)(1)(v) of this section. The characteristics of the Safe Shutdown Earthquake shall be derived from more than one earthquake determined from paragraph (a)(1)(i) through (iii) of this section, where necessary to assure that the maximum vibratory acceleration at the site throughout the frequency range of interest is included. In the case where a causative fault is near the site, the effect of proximity of an earthquake on the spectral characteristics of the Safe Shutdown Earthquake shall be taken into account. The procedures in paragraphs (a)(1)(i) through (a)(1)(iii) of this section shall be applied in a conservative manner. The determinations carried out in accordance with paragraphs (a)(1)(ii) and (a)(1)(iii) shall assure that the safe shutdown earthquake intensity is, as a minimum, equal to the maximum historic earthquake intensity experienced within the tectonic province in which the site is located. In the event that geological and seismological data warrant, the Safe Shutdown Earthquake shall be larger than that derived by use of the procedures set forth in section IV and V of the appendix. The maximum vibratory accelerations of the Safe Shutdown Earthquake at each of the various foundation locations of the nuclear power plant structures at a given site shall be determined taking into account the characteristics of the underlying soil material in transmitting the earthquake-induced motions, obtained pursuant to paragraphs (a)(1), (3), and (4) of section IV. The Safe Shutdown Earthquake shall be defined by response spectra corresponding to the maximum vibratory accelerations as outlined in paragraph (a) of section VI; and

(v) Where the maximum vibratory accelerations of the Safe Shutdown Earthquake at the foundations of the nuclear power plant structures are determined to be less than one-tenth the acceleration of gravity (0.1 g) as a result of the steps required in paragraphs (a)(1)(i) through (iv) of this section, it shall be assumed that the maximum vibratory accelerations of the Safe Shutdown Earthquake at these foundations are at least 0.1 g.

(2) *Determination of Operating Basis Earthquake*. The Operating Basis Earthquake shall be specified by the applicant after considering the seismology and geology of the region surrounding the site. If vibratory ground motion exceeding that of the Operating Basis Earthquake occurs, shutdown of the nuclear power plant will be required. Prior to resuming operations, the licensee will be required to demonstrate to the Commission that no functional damage has occurred to those features necessary for continued operation without undue risk to the health and safety of the public.

The maximum vibratory ground acceleration of the Operating Basis Earthquake shall be at least one-half the maximum vibratory ground acceleration of the Safe Shutdown Earthquake.

(b) *Determination of Need to Design for Surface Faulting*. In order to determine whether a nuclear power plant is required to be designed to withstand the effects of surface faulting, the location of the nuclear power plant with respect to capable faults shall be considered. The area over which each of these faults has caused surface faulting in the past is identified by mapping its fault traces in the vicinity of the site. The fault traces are mapped along the trend of the fault for 10 miles in both directions from the point of its nearest approach to the nuclear power plant because, for example, traces may be obscured along portions of the fault. The maximum width of the mapped fault traces, called the control width, is then determined from this map. Because surface faulting has sometimes occurred beyond the limit of mapped fault traces or where fault traces have not been previously recognized, the control width of the fault is increased by a factor which is dependent upon the largest potential earthquake related to the fault. This larger width delineates a zone, called the zone requiring detailed faulting investigation, in which the possibility of surface faulting is to be determined. The following paragraphs outline the specific procedures for determining the zone requiring detailed faulting investigation for a capable fault.

(1) *Determination of Zone Requiring Detailed Faulting Investigation*. The zone requiring detailed faulting investigation for a capable fault which was investigated pursuant to the requirement of paragraph (b)(7) of section IV shall be determined through use of the following table:

Magnitude of earthquake	**Width of zone requiring detailed faulting investigation (see fig. 1)**
Less than 5.5	1 x control width.
5.5-6.4	2 x control width.
6.5-7.5	3 x control width.
Greater than 7.5	4 x control width.

The largest magnitude earthquake related to the fault shall be used in table 2. This earthquake shall be determined from the information developed pursuant to the requirements of paragraph (b) of Section IV for the fault, taking into account the information required by paragraph (b)(7) of section IV. The control width used in table 2 is determined by mapping the outer limits of the fault traces from information developed pursuant to paragraph (b)(7)(iv) of section IV. The control width shall be used in table 2 unless the characteristics of the fault are obscured for a significant portion of the 10 miles on either side of the point of nearest approach to the nuclear power plant. In this event, the use in table 2 of the width of mapped fault traces more than 10 miles from the point of nearest approach to the nuclear power plant may be appropriate.

The zone requiring detailed faulting investigation, as determined from table 2, shall be used for the fault except where:

(i) The zone requiring detailed faulting investigation from table 2 is less than one-half mile in width. In this case the zone shall be at least one-half mile in width; or

(ii) Definitive evidence concerning the regional and local characteristics of the fault justifies use of a different value. For example, thrust or bedding-plane faults may require an increase in width of the zone to account for the projected dip of the fault plane; or

(iii) More detailed three-dimensional information, such as that obtained from precise investigative techniques, may justify the use of a narrower zone. Possible examples of such techniques are the use of accurate records from closely spaced drill holes or from closely spaced, high-resolution offshore geophysical surveys.

In delineating the zone requiring detailed faulting investigation for a fault, the center of the zone shall coincide with the center of the fault at the point of nearest approach of the fault to the nuclear power plant as illustrated in figure 1.

(c) *Determination of Design Bases for Seismically Induced Floods and Water Waves*. The size of seismically induced floods and water waves which could affect a site from either locally or distantly generated seismic activity shall be determined, taking into consideration the results of the investigation required by paragraph (c) of section IV. Local topographic characteristics which might tend to modify the possible runup and drawdown at the site shall be considered. Adverse tide conditions shall also be taken into account in determining the effect of the floods and waves on the site. The characteristics of the earthquake to be used in evaluating the offshore effects of local earthquakes shall be determined by a procedure similar to that used to determine the characteristics of the Safe Shutdown Earthquake in paragraph V(a).

(d) *Determination of Other Design Conditions*—(1) *Soil Stability*. Vibratory ground motion associated with the Safe Shutdown Earthquake can cause soil instability due to ground disruption such as fissuring, differential consolidation, liquefaction, and cratering which is not directly related to surface faulting. The following geologic features which could affect the foundations of the proposed nuclear power plant structures shall be evaluated, taking into account the information concerning the physical properties of materials underlying the site developed pursuant to paragraphs (a)(1), (3), and (4) of section IV and the effects of the Safe Shutdown Earthquake:

(i) Areas of actual or potential surface or subsurface subsidence, uplift, or collapse resulting from:

(a) Natural features such as tectonic depressions and cavernous or karst terrains, particularly those underlain by calcareous or other soluble deposits;

(b) Man's activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams or reservoirs; and

(c) Regional deformation.

(ii) Deformational zones such as shears, joints, fractures, folds, or combinations of these features.

(iii) Zones of alteration or irregular weathering profiles and zones of structural weakness composed of crushed or disturbed materials.

(iv) Unrelieved residual stresses in bedrock.

(v) Rocks or soils that might be unstable because of their mineralogy, lack of consolidation, water content, or potentially undesirable response to seismic or other events. Seismic response characteristics to be considered shall include liquefaction, thixotropy, differential consolidation, cratering, and fissuring.

(2) *Slope stability*. Stability of all slopes, both natural and artificial, the failure of which could adversely affect the nuclear power plant, shall be considered. An assessment shall be made of the potential effects of erosion or deposition and of combinations of erosion or deposition with seismic activity, taking into account information concerning the physical property of the materials underlying the site developed pursuant to paragraph (a)(1), (3), and (4) of section IV and the effects of the Safe Shutdown Earthquake.

(3) *Cooling water supply*. Assurance of adequate cooling water supply for emergency and long-term shutdown decay heat removal shall be considered in the design of the nuclear power plant, taking in to account information concerning the physical properties of the materials underlying the site developed pursuant to paragraphs (a)(1), (3), and (4) of section IV and the effects of the Safe Shutdown Earthquake and the design basis for surface faulting. Consideration of river blockage or diversion or other failures which may block the flow of cooling water, coastal uplift or subsidence, or tsunami runup and drawdown, and failure of dams and intake structures shall be included in the evaluation, where appropriate.

(4) *Distant structures*. Those structures which are not located in the immediate vicinity of the site but which are safety related shall be designed to withstand the effect of the Safe Shutdown Earthquake and the design basis for surface faulting determined on a comparable basis to that of the nuclear power plant, taking into account the material underlying the structures and the different location with respect to that of the site.

VI. Application to Engineering Design

(a) *Vibratory ground motion*—(1) *Safe Shutdown Earthquake*. The vibratory ground motion produced by the Safe Shutdown Earthquake shall be defined by response spectra corresponding to the maximum vibratory accelerations at the elevations of the foundations of the nuclear power plant structures determine pursuant to paragraph (a)(1) of section V. The response spectra shall relate the response of the foundations of the nuclear power plant structures to the vibratory ground motion, considering such foundations to be single-degree-of-freedom damped oscillators and neglecting soil-structure interaction effects. In view of the limited data available on vibratory ground motions of strong earthquakes, it usually will be appropriate that the response spectra be smoothed design spectra developed from a series of response spectra related to the vibratory motions caused by more than one earthquake.

The nuclear power plant shall be designed so that, if the Safe Shutdown Earthquake occurs, certain structures, systems, and components will remain functional. These structures, systems, and components are those necessary to assure (i) the integrity of the reactor coolant pressure boundary, (ii) the capability to shut down the reactor and maintain it in a safe condition, or (iii) the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the guideline exposures of this part. In addition to seismic loads, including aftershocks, applicable concurrent functional and accident-induced loads shall be taken into account in the design of these safety-related structures, systems, and components. The design of the nuclear power plant shall also take into account the possible effects of the Safe Shutdown Earthquake on the facility foundations by ground disruption, such as fissuring, differential consolidation, cratering, liquefaction, and landsliding, as required in paragraph (d) of section V.

The engineering method used to insure that the required safety functions are maintained during and after the vibratory ground motion associated with the Safe Shutdown Earthquake shall involve the use of either a suitable dynamic analysis or a suitable qualification test to demonstrate that structures, systems and components can withstand the seismic and other concurrent loads, except where it can be demonstrated that the use of an equivalent static load method provides adequate conservatism.

The analysis or test shall take into account soil-structure interaction effects and the expected duration of vibratory motion. It is permissible to design for strain limits in excess of yield strain in some of these safety-related structures, systems, and components during the Safe Shutdown Earthquake and under the postulated concurrent conditions, provided that the necessary safety functions are maintained.

(2) *Operating Basis Earthquake*. The Operating Basis Earthquake shall be defined by response spectra. All structures, systems, and components of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public shall be designed to remain functional and within applicable stress and deformation limits when subjected to the effects of the vibratory motion of the Operating Basis Earthquake in combination with normal operating loads. The engineering method used to insure that these structures, systems, and components are capable of withstanding the effects of the Operating Basis Earthquake shall involve the use of either a suitable dynamic analysis or a suitable qualification test to demonstrate that the structures, systems and components can withstand the seismic and other concurrent loads, except where it can be demonstrated that the use of an equivalent static load method provides adequate conservatism. The analysis or test shall take into account soil-structure interaction effects and the expected duration of vibratory motion.

(3) *Required Seismic instrumentation*. Suitable instrumentation shall be provided so that the seismic response of nuclear power plant features important to safety can be determined promptly to permit comparison of such response with that used as the design basis. Such a comparison is needed to decide whether the plant can continue to be operated safely and to permit such timely action as may be appropriate.

These criteria do not address the need for instrumentation that would automatically shut down a nuclear power plant when an earthquake occurs which exceeds a predetermined intensity. The need for such instrumentation is under consideration.

(b) *Surface Faulting*. (1) If the nuclear power plant is to be located within the zone requiring detailed faulting investigation, a detailed investigation of the regional and local geologic and seismic characteristics of the site shall be carried out to determine the need to take into account surface faulting in the design of the nuclear power plant. Where it is determined that surface faulting need not be taken into account, sufficient data to clearly justify the determination shall be presented in the license application.

(2) Where it is determined that surface faulting must be taken into account, the applicant shall, in establishing the design basis for surface faulting on a site take into account evidence concerning the regional and local geologic and seismic characteristics of the site and from any other relevant data.

(3) The design basis for surface faulting shall be taken into account in the design of the nuclear power plant by providing reasonable assurance that in the event of such displacement during faulting certain structures, systems, and components will remain functional. These structures, systems, and components are those necessary to assure (i) the integrity of the reactor coolant pressure boundary, (ii) the capability to shut down the reactor and maintain it in a safe shutdown condition, or (iii) the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the guideline exposures of this part. In addition to seismic loads, including aftershocks, applicable concurrent functional and accident-induced loads shall be taken into account in the design of such safety features. The design provisions shall be based on an assumption that the design basis for surface faulting can occur in any direction and azimuth and under any part of the nuclear power plant unless evidence indicates this assumption is not appropriate, and shall take into account the estimated rate at which the surface faulting may occur.

(c) *Seismically Induced Floods and Water Waves and Other Design Conditions*. The design basis for seismically induced floods and water waves from either locally or distantly generated seismic activity and other design conditions determined pursuant to paragraphs (c) and (d) of section V, shall be taken into account in the design of the nuclear power plant so as to prevent undue risk to the health and safety of the public.

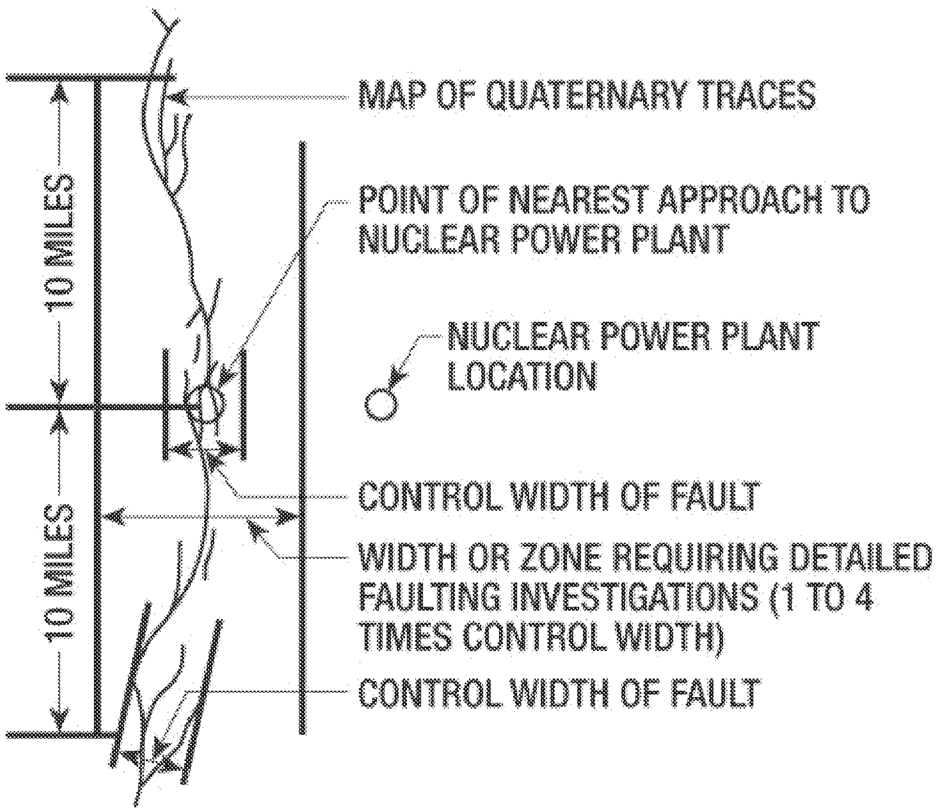

Figure 1--Diagrammatic Illustration of Delineation of Width of Zone Requiring Detailed Faulting Investigations For Specific Nuclear Power Plant Location.

(Sec. 201, Pub. L. 93-438, 88 Stat. 1243 (42 U.S.C. 5841))

[38 FR 31281, Nov. 13, 1973, as amended at 38 FR 32575, Nov. 27, 1973; 42 FR 2052, Jan. 10, 1977; 78 FR 34250, Jun. 7, 2013]

[1] The Safe Shutdown Earthquake defines that earthquake which has commonly been referred to as the Design Basis Earthquake.

[2] If the Safe Shutdown Earthquake can be associated with a fault closer than 200 miles to the site, the procedures of paragraphs (a)(7) and (a)(8) of this section need not be carried out for successively more remote faults.

[3] In the absence of absolute dating, evidence of recency of movement may be obtained by applying relative dating technique to ruptured, offset, warped or otherwise structurally disturbed surface or near surface materials or geomorphic features.

[4] The applicant shall evaluate whether or not a fault is a capable fault with respect to the characteristics outlined in paragraphs III(g)(1), (2), and (3) by conducting a reasonable investigation using suitable geologic and geophysical techniques.

[5] If the design basis for surface faulting can be determined from a fault closer than 5 miles to the site, the procedures of paragraphs (b)(4) through (b)(7) of this section need not be carried out for successively more remote faults.

[6] In the absence of absolute dating, evidence of recency of movement may be obtained by applying relative dating techniques to ruptured, offset, warped or otherwise structurally disturbed surface of near-surface materials or geomorphic features.

[7] The applicant shall evaluate whether or not a fault is a capable fault with respect to the characteristics outlined in paragraphs III(g)(1), (2), and (3) by conducting a reasonable investigation using suitable geological and geophysical techniques.

Page Last Reviewed/Updated Tuesday, August 29, 2017

STRUCTURE

The Jewel Cave SW quadrangle is on the southwest side of the broad domal Black Hills uplift. The sedimentary rocks in the area generally dip from 2° to 4° SW. Structural features superimposed upon this regional dip are: the east-northeast-trending Dewey fault, two northwest-trending anticlines, contortion of bedding and other minor structures resulting from subsidence, and minor structures in the Permian and Triassic rocks that have probably resulted from sliding of the rocks parallel to the dip.

DEWEY FAULT

The most conspicuous structural feature in the quadrangle is the rather sinuous Dewey fault that extends across the center of the quadrangle; it has a trend of about N. 75° E. The fault is known to extend at least 6 miles to the southwest (Brobst, 1961, p. 51), but its northern extension is unknown. The fault is exposed at only one place, the gully. in the SW1/4NE1/4 sec. 10, T. 6 S., R. 1 E., and here it seems to be vertical. Elsewhere the fault can be recognized by the steep dips in the beds along it and by the omission of strata on the south side. The rocks on the south side of the fault have apparently been displaced downward. The amount of displacement varies, but the maximum displacement is near the west side of the quadrangle. The movement has been accomplished by separation along the fault and by bending of strata adjacent to the fault. The cross sections of figure 49 illustrate the apparent displacement. Along section B—B' the total stratigraphic displacement, including that caused by bending, is about 440 feet; and along section D—D' the total stratigraphic displacement is about 250 feet. Because of the rather sinuous trend of the fault, it seems most likely that the major component of movement was parallel to the dip of the fault.

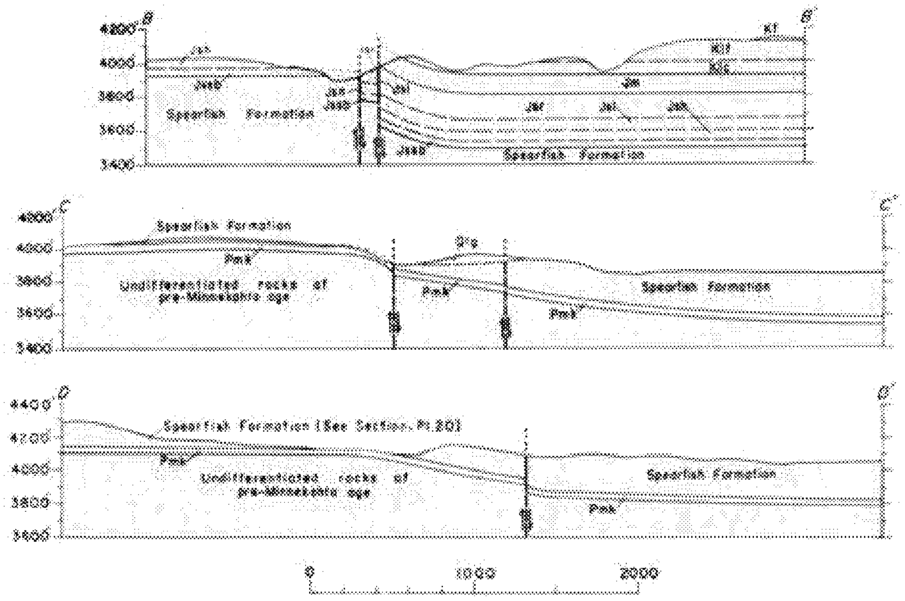

FIGURE 49.—Sections of the Dewey fault. Locations of sections shown on plate 20. Qtg, terrace gravel of Quaternary age; Kf, Fall River Formation; Klf, Fuson Member of Fall River Formation; Klc, Chilson Member of Lakota Formation; Jm, Morrison Formation; Jsr, Redwater Shale Member, Jsl, Lak Formation, Jsh, Hulett Sandstone Member, Jssb, Stockade Beaver Shale Member, all of the Sundance Formation; Pmk, Minnekahta Limestone. *(click on image for a PDF version)*

NORTHWEST-TRENDING ANTICLINES

Two broad, gentle anticlines are present in the quadrangle. The southernmost anticline extends from sec. 2, T. 7 S., R. 2 E. in the Edgemont NE quadrangle southeast of the Jewel Cave SW quadrangle to sec. 34, T. 5 S., R. 1 E. in the Jewel Cave SW quadrangle—a total distance of about 10 miles. Throughout this distance the trend of the axis of the fold, which changes from about N. 50° W. at the south to about N. 40° W. at the north, is very, nearly parallel to the regional strike of the formations. The northernmost of the two anticlines extends for only 3 miles between Hell Canyon and Tepee Canyon. The trend of the axis is about N. 45° W., roughly parallel to the regional strike. The dips on the limbs of these folds are small; they range from about 6° to 13°. At several places the northeast-dipping limbs are somewhat steeper than the southwest limbs.

There are several areas of closure on the folds. On the northern fold the closure is about 110 feet. The axis of the southern fold, although nearly horizontal, undulates gently and produces long areas of closure. Southeast of the Jewel Cave SW quadrangle, in the Edgemont NE quadrangle, oil has been produced from the lower part of the Minnelusa Formation on the closure that marks the south limit of the fold. The center of sec. 7, T. 6 S., R. 2 E. is the crest of an area of inferred closure of about 30 feet on the base of the Sundance Formation. In this area rocks of the upper part of the Spearfish Formation crop out, but are very poorly exposed; thus the delineation of the shape of this part of the structure is uncertain. Just north of the Dewey fault there is a closure of at least 120 feet on the top of the Minnekahta Limestone; the closure is due largely to drag along the fault. The casing of an abandoned well (listed by the Conservation Division, U.S. Geol. Survey, as "L. Gokel, Pass Creek well, drilled 1935, abandoned Jan. 1936, T.D. 1035") is visible on the crest of this part of the structure.

SUBSIDENCE STRUCTURAL FEATURES

In the Jewel Cave SW quadrangle many minor structural features were caused by the subsidence of overlying units when large volumes of soluble sediments were dissolved, principally from the Minnelusa Formation. N. H. Darton mentioned the presence of breccias in the Minnelusa at several localities in the Black Hills, but he did not give any interpretation of them. In 1930 F. H. Brady[4] described the transition from an area containing about 150 feet of gypsum to an area of brecciation in the northern part of the Black Hills, but he did not explain the origin of the breccias, and he interpreted the termination of the gypsum beds as a primary depositional feature. Breccias in the Minnelusa in the southern part of the Black Hills were ascribed to tectonic forces by P. M. Work.[5] The breccias, which are present in the type section of the Minnelusa along Rapid Creek, were interpreted by D. C. Boardman[6] as having originated by leaching of anhydrite from the formation. J. P. Gries (1952, p. 71) expressed the view that:

> Although it has been suggested that up to 200 feet of anhydrite and carbonate is missing in the outcrop sections, recent studies show very small discrepancies between outcrop measurements and nearby subsurface thicknesses. Lack of extensive "collapse" or brecciated sections, and an increase in the quantity of clastics in the outcrops suggest that deposition of clastics over the site of the Black Hills occurred simultaneously with the precipitation of evaporites in the adjacent areas.

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[4]F. H. Brady, 1930, Some problems of the Minnelusa formation near Beulah, Wyoming: Iowa Univ. M.S. thesis.

[5]P. M. Work, 1931, Stratigraphy and paleontology of the Minnelusa, formation of the southern Black Hills of South Dakota: Iowa Univ. M.S. thesis.

[6]D. C. Boardman 1942, Minnelusa formation in Rapid Canyon area, Black Hills, South Dakota: Iowa Univ. M.S. thesis.

In a recent publication, R. L. Bates (1955) describes breccias both in the Black Hills and in the Hartville uplift in Wyoming. He interprets these breccias as being the result of solution of anhydrite "penecontemporaneous" with their deposition in Permian time.

The subsidence structures in the Jewel Cave SW quadrangle include: collapse breccias in the Minnelusa, residual limestone-dolomite breccias in the Spearfish, undulations and normal faults in the formations overlying the Minnelusa, and breccia pipes that extend upward from the Minnelusa at least as high in the stratigraphic section as the Lakota Formation.

COLLAPSE BRECCIAS IN THE MINNELUSA FORMATION

The strata of the upper part of the Minnelusa Formation in the northeast corner of the quadrangle are extensively fractured, brecciated, and contorted. The highest bed in the Minnelusa is only moderately deformed, as are the overlying formations. The thick sandstone at the top of the Minnelusa (pl. 21) changes downward from almost undeformed rock to highly fractured rock and finally to breccia in which the fragments have been rotated and mixed to a minor extent with fragments of the underlying unit. Below this sandstone is about 300 feet of highly deformed rocks. Individual strata of limestone, sandstone, or siltstone are moderately to intensely brecciated and markedly contorted. The former positions of anhydrite beds can be identified in most places because weakly brecciated beds are overlain by beds that are intensely brecciated at the base and that grade upward into less intensely brecciated rock.

The contortion of strata is made apparent by the alternation of thin resistant carbonate rock units and nonresistant sandstone units. The carbonate beds maintain a relatively uniform thickness, but the intervening sandstone varies appreciably in thickness. Beds of sandstone may range in thickness from 2 to 16 feet in a horizontal distance of about 30 feet. This variation in thickness must be the result of the poorly cemented sandstone's having been squeezed into areas from which anhydrite was being removed.

In several places, intrusive masses of rock resembling conglomerate occur along the contact between beds. This conglomeratic-looking rock probably resulted from the partial milling of breccia fragments of sandstone as it was squeezed into its present position. In addition to being brecciated and undulatory, thick beds of sandstone are broken by many small vertical or steep gravity faults.

Many of the above-described features are shown in figure 50, which was photographed in Hell Canyon northeast of the mapped area. As shown in this picture, the rocks at the base of the cliff are brecciated and fractured only to a minor degree. These rocks occupy a position below that part of the Minnelusa that in the subsurface contains abundant anhydrite. It can be inferred that below this horizon only thin beds of anhydrite were present, because only a few thin units are brecciated.

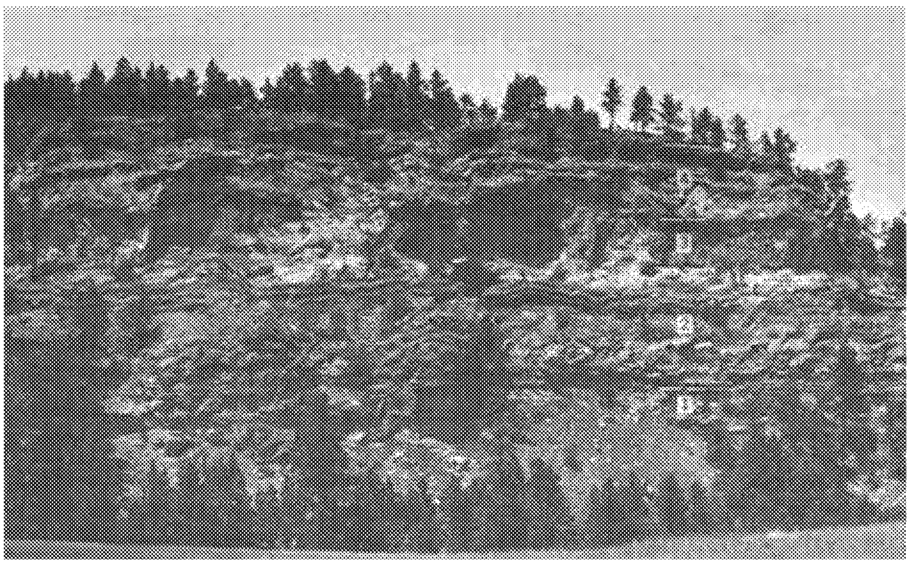

FIGURE 50.—Lower part of the collapse breccia in the Minnelusa Formation in sec. 3, T. 5 S., R. 2 E., Jewel Cave quadrangle. The numbered units correspond to those shown In the upper Hell Canyon columnar section of plate 21.

All the anhydrite has probably been leached from the Minnelusa Formation in the northeast corner of the Jewel Cave SW quadrangle. The downdip limit of complete leaching as located on plate 20 is based on several facts: The exposures of the Minnelusa in Hell Canyon, in the NE1/4 sec. 31, T. 5 S., R. 2 E., contain gypsum beds and are not brecciated. The boundary of extensive solution must lie updip from these exposures. There is a noticeable concentration of breccia pipes in the northeast corner of the quadrangle, and the bounding line was placed downdip from this concentration.

A gentle structural depression extending more than 3,000 feet along the east side of sec. 9, T. 6 S., R. 2 E. (pl. 20) contains a large collapse pipe. In this depression the base of the Hulett Sandstone Member of the Sundance may be downwarped as much as 100 feet (fig. 52). It seems probable that the depression overlies an isolated area from which anhydrite was dissolved from the Minnelusa Formation.

BRECCIAS IN THE SPEARFISH FORMATION

The G_2 and G_3 gypsum beds in the lower half of the Spearfish Formation are absent in the northeast corner of the Jewel Cave SW quadrangle. North of the boundary line shown on plate 20 the equivalent positions of the gypsum beds are occupied by 3- to 10-foot-thick beds that consist of fragments of dolomite and limestone in a matrix of red siltstone. The transition from gypsum to dolomite, as observed in two places, occurs within a horizontal distance of about 300 feet.

UNDULATIONS AND NORMAL FAULTS IN THE MINNEKAHTA LIMESTONE

Subsidence structures are particularly noticeable in the Minnekahta Limestone, which is the first resistant unit above the Minnelusa. Throughout much of the northeast corner of the quadrangle the Minnekahta Limestone crops out on dip slopes. The area of extensive outcrop overlies the breccia zone of the Minnelusa in the northeast and the unbrecciated Minnelusa in the central part of the quadrangle. A difference in the character of the outcrop is progressively evident toward the areas of extensive subsidence. The Minnekahta Limestone is distinctly undulatory where it overlies breccia in the Minnelusa. Irregular domes alternating with bowl-shaped depressions are common. The size of the individual basins or domes is variable; the largest are about 500 to 1,000 feet in diameter and have amplitudes of a few tens of feet. Commonly, small domes or basins are superimposed on larger ones. The structure contours in the northeast corner of the map (pl. 20) are based largely on elevations on top of the Minnekahta. No attempt was made to smooth or generalize the contours when they were converted to the base of the Hulett, because it was desired to illustrate the subsidence deformation. The shape of the contours in secs. 17, 18, and 20, T. 5 S., R. 2 E., are considered to be typical of the areas underlain by extensive collapse. The contours in secs. 25, T. 5 S., R. 1 E., and 30, and 31, T. 5 S., R. 2 E., along the anticline, are based on the top of the Minnekahta Limestone also, and are considerably smoother. This area is believed to be underlain by unbrecciated Minnelusa.

On the walls of Hell Canyon in secs. 16, 17, 20, 21, and 29, T. 5 S., R. 2 E., the undulations can be seen in cross section. On these cliffs many small faults are exposed, but none of the faults can be traced away from the canyon walls.

BRECCIA PIPES

Breccia pipes are vertical, nearly cylindrical bodies within which the rock has subsided more than the surrounding rock. They are most abundant in the northeast corner of the quadrangle, but a few pipes have been found as much as 4 miles downdip from the area of complete leaching. The locations of all known pipes are shown on plate 20.

The appearance of the breccia pipes varies. Those that penetrate the upper part of the Minnelusa Formation are generally small; they range from about 10 to 100 feet in diameter and are filled with a breccia consisting of limestone or calcareous sandstone fragments set in a matrix of calcareous sandstone.

Breccia pipes that penetrate the Minnekahta Limestone range in size from a diameter of about 40 feet (fig. 51) to a maximum observed diameter of about 300 feet. The Minnekahta Limestone within the pipes is characteristically intensely brecciated. The amount of downward movement of the Minnekahta could be estimated in two pipes; in one the displacement exceeds 80 feet, and in the other the displacement is about 100 feet. In several places coalescing groups of pipes suggest that joint sets, striking about N. 80° E. and N. 50° W., have localized the solution of underlying rock.

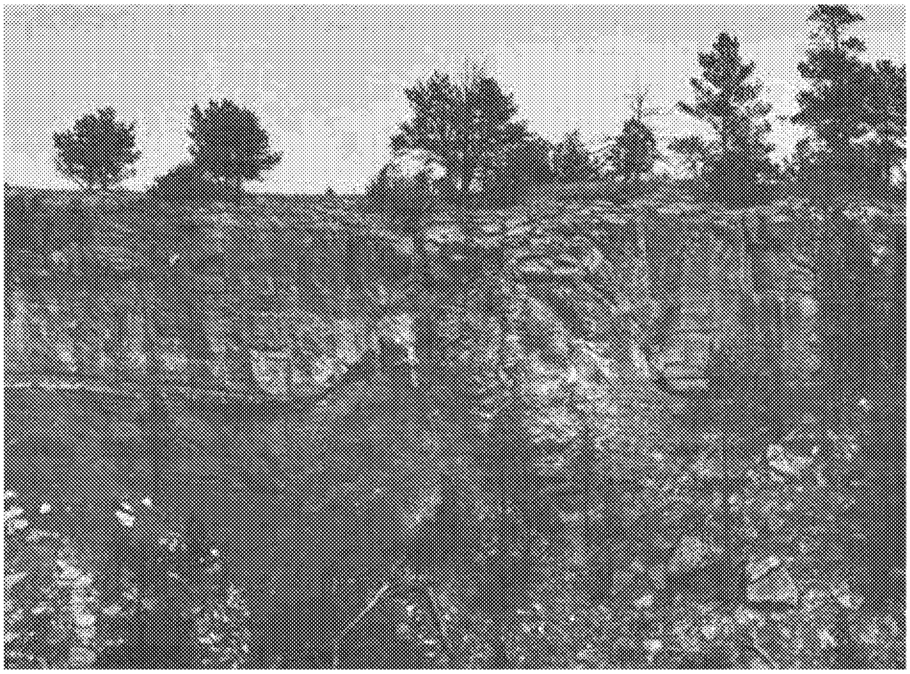

FIGURE 51.—Small breccia pipe that penetrates the Minnekahta Limestone in the SE1/4 sec. 25, T. 5 S., R. 1 E. Small normal faults cut Opeche-Minnekahta contact at left side of pipe.

Several breccia pipes having diameters of about 50 feet penetrate the Spearfish Formation. These pipes are filled with fragments of dolomite from the overlying gypsum beds of the Spearfish set in a matrix of calcareous red siltstone. Because of the calcite cement, some of these pipes are more resistant than the surrounding siltstone and stand 15 to 20 feet above the ground level.

The largest pipe within the quadrangle penetrates the base of the Sundance Formation in the northeast corner of sec. 9, T. 6 S., R. 2 E. Where the pipe penetrates the Canyon Springs Sandstone Member, it is approximately 450 feet in diameter. The vertical displacement at this level is about 70 feet (fig. 52). The Hulett Sandstone Member in the center of the pipe is not brecciated, but dips gently inward toward the center of the pipe.

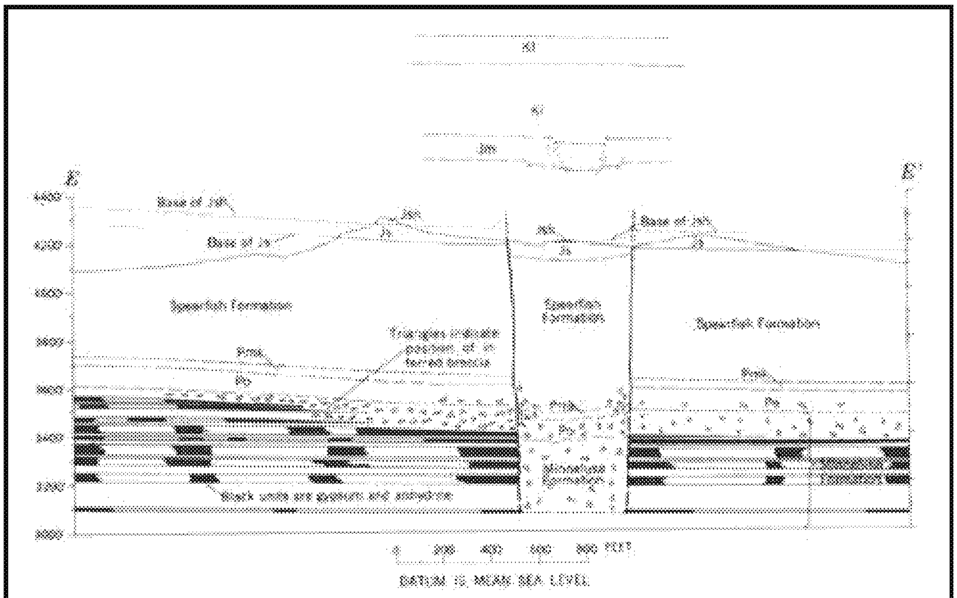

FIGURE 52.—Cross section *E*—*E'* of plate 20 showing inferred extent of breccia

pipe. Jsh, Hulett Sandstone Member of Sundance Formation; Js, Sundance Formation; Pmk, Minnekahta Formation; Po, Opeche Formation. *(click on image for a PDF version)*

Several breccia pipes are known to penetrate as high as the lower part of the Lakota Formation. One of these pipes is in the Edgemont NE quadrangle, and has a vertical displacement of about 60 feet (G. B. Gott, oral communication, 1958). Another is in the NE1/4 sec. 24, T. 6 S., R. 1 E., in the Jewel Cave SW quadrangle. This pipe is marked only by a conical downwarp of the strata in the base of the Lakota. Subsidence in this pipe probably did not extend much higher into the Lakota.

ORIGIN OF SUBSIDENCE STRUCTURES

All the structures described are clearly related to the removal of soluble rocks from underlying formations. The logs of many wells that penetrate the Minnelusa Formation around the periphery of the Black. Hills have been published by the Geological Survey of South Dakota (Baker, 1947, 1948, 1951). All but two wells contained an hydrite. The anhydrite, which is present in many thin beds, is concentrated in the upper half of the Minnelusa Formation. A few beds less than 5 feet thick are in the lower half of the formation. The total thickness of anhydrite in the upper half of the formation ranges from about 100 feet north of the Black Hills to about 300 feet at the southern end of the Black Hills.

Most of the described collapse features are due to the solution of anhydrite from the upper part of the Minnelusa. The brecciated parts of the Minnelusa in the outcrop are at the same stratigraphic position as the major anhydrite beds in the subsurface. Only minor breccias or subsidence structures occur below the middle of the Minnelusa, and these are due to solution of a few thin beds of anhydrite that occur in the lower part of the Minnelusa.

Subsidence structures above the middle part of the Spearfish Formation may be due to, or augmented by, leaching of about 60 feet of anhydrite from the lower part of the Spearfish Formation.

TIME OF LEACHING

The leaching of anhydrite from the Minnelusa Formation must have occurred at some time after the Early Cretaceous, because breccia pipes penetrate strata as young as Early Cretaceous. From Early Cretaceous time until uplift of the region in Late Cretaceous and early Cenozoic time, anhydrite-bearing sediments were buried beneath more than 3,000 feet of nearly horizontal sediments. The sedimentary cover of the center of the Black Hills had been tilted and eroded down to the Precambrian rocks by the Oligocene Epoch, and probably earlier, and thus artesian circulation may have-been established in the anhydrite-bearing units early in the Cenozoic Era. The climate of this region during the early Cenozoic is believed to have been more humid than it was during the later part of the period (Brown, 1952, p. 91), and solution as extensive as that described would be facilitated by a humid climate. Solution features produced under the semiarid climate, which exists today, are very minor in the gypsum beds of the Spearfish Formation. Thus it seems probable that the major part of the leaching was accomplished in the early part of the Cenozoic, although solution on a limited scale may have continued to the present time.

MINOR DEFORMATIONAL STRUCTURAL FEATURES IN THE MINNEKAHTA LIMESTONE AND SPEARFISH FORMATION

In addition to the subsidence features previously described, a group of structural features occurs in the Minnekahta Limestone and Spearfish Formation that are believed to have been produced by slippage of the formations downdip. This group includes small thrust faults and related minor folds, dolomite breccias, pull apart structures, small tight folds in thin gypsum beds, and cross folds.

Description of structural features.—Thrust faults of small displacement and associated minor folds occur throughout the outcrop area of the Minnekahta Limestone. The observed displacements on the faults range from several inches to about 3 feet (fig. 53). The faults may be either smooth planes having slickensides parallel to the dip of the faults, or they may be narrow brecciated zones. Where the fault displacement has taken place through a zone instead of along a single surface, the thin strata of the Minnekahta have been rotated around an axis parallel to the strike of the fault. Intense rotation has produced a brecciated zone; less intense rotation has produced asymmetric minor folds. In the latter, the steeply dipping limb of the fold is parallel to the thrust fault zone. Some of the faults cut entirely across the Minnekahta; others are restricted to the Minnekahta and die out both upward and downward within the formation.

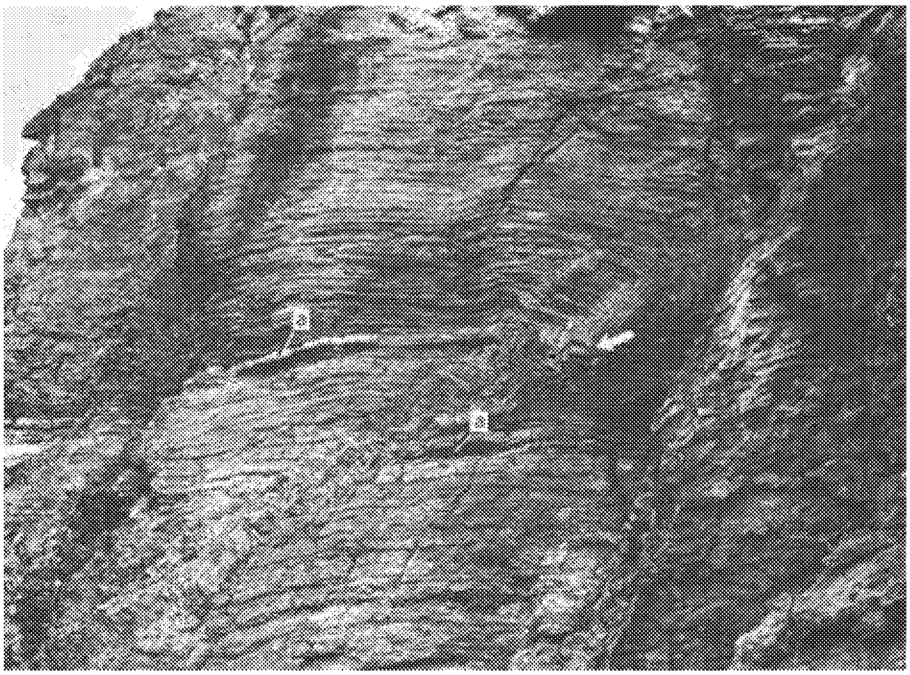

FIGURE 53.—Thrust fault that passes upward into small fold. Minnekahta Limestone, SW1/4 sec. 9, T. 5 S., R. 2 E. The displacement is shown by offset of the conspicuous bed (a). View looking northwest. Arrow points to hat for scale.

The strike of the thrust faults and the axes of the associated minor folds have a preferred orientation of about N. 45° W., which is almost parallel to the direction of strike of the formations in the vicinity (fig. 54). The thrust faults dip about 45° either to the northeast or to the southwest.

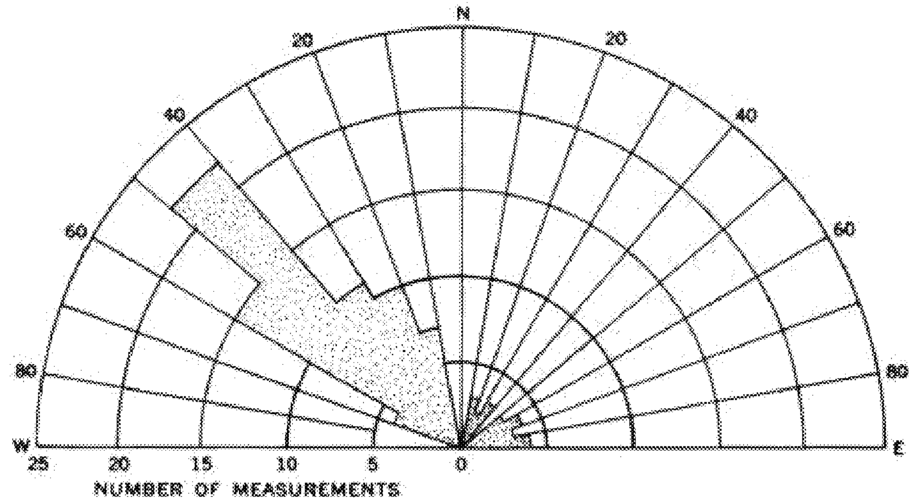

FIGURE 54.—Bearing of the axes of 92 minor folds in the Minnekahta Limestone, Jewel Cave SW quadrangle.

A varying thickness of thinly laminated dolomite commonly occurs in the Spearfish Formation at the base of gypsum bed G_2 (fig. 44). In many exposures the dolomite is extensively brecciated. At some places small northwest-striking thrust faults extend from the brecciated dolomite upward into the overlying gypsum.

The structure shown on the right side of figure 55 is termed a "pull-apart" structure by the writer. The basal bed of the G_3 gypsum in the Spearfish Formation has been pulled apart a distance of about 40 feet, and the underlying siltstone and thin gypsum beds have been forced upward into its former position. The third dimension of this structure could not be observed. Smaller examples of pull-apart structures in thin gypsum beds are shown in figure 56.

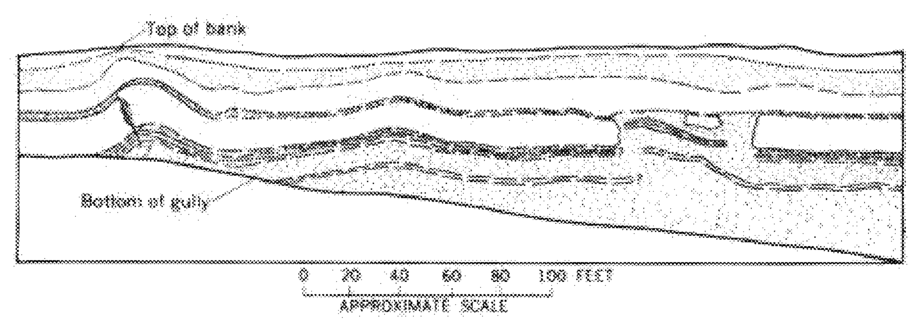

FIGURE 55.—Deformed gypsum beds in the Spearfish Formation. Stippled areas are siltstone. SW1/4 sec. 26, T. 5 S., R. 1 E. Looking northeast.

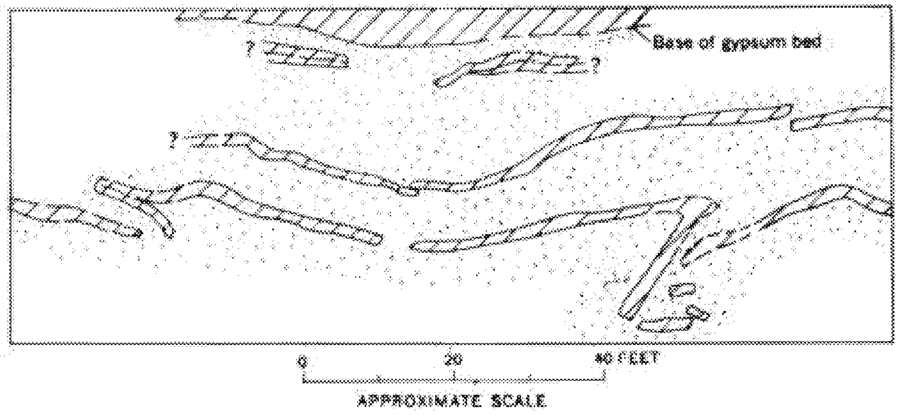

FIGURE 56.—cross section of thin contorted gypsum beds underlying G_3 gypsum bed of the Spearfish. Stippled area is siltstone. NE 1/4 sec. 35, T. 5 S., R. 1 E. Looking northeast.

At many localities in the Spearfish Formation the thin beds of gypsum between beds G_2 and G_3 are tightly folded. The folds range from small symmetrical folds, having amplitudes of about 1 foot, to overturned and recumbent folds like those shown in figure 56.

Several sharp anticlines and synclines that trend at nearly right angles to the regional strike occur in the Minnekahta Limestone in the northeast quarter of the quadrangle. An anticline that trends about N. 30° E. begins in the SE1/4 sec. 28, T. 5 S., R. 2 E., and extends for at least 1 mile to the northeast (pl. 20). The Spearfish Formation is flexed at the southern end of this fold. A sharp V-shaped syncline extends from the middle of sec. 31, T. 5 S., R. 2 E., to the SE1/4 sec. 36, T. 5 S., R. 1 E. It is paralleled on the north side of Hell Canyon by several smaller synclines that have similar shapes.

The G_3 gypsum bed in the Spearfish has been folded to form an arcuate syncline-anticline pair in sec. 26, T. 5 S., R. 1 E. (pl. 20). Near the center, and at the southern boundary of sec. 26, several reverse faults too small to be mapped occur just east of the synclinal trough (left side of fig. 55). The syncline exposed in the eastern part of sec. 34, T. 5 S., R. 1 E., may be a continuation of the folds in sec. 26.

Origin of the minor deformational structures.—Possible mechanisms of formation of the minor structural features are irregular subsidence due to leaching of anhydrite, deformation due to expansion when anhydrite was converted to gypsum, plastic flowage of beds of gypsum, and deformation as a result of sliding of large masses of rock.

In the northeast corner of the quadrangle all the anhydrite originally present in the Minnelusa, Opeche, and Spearfish Formations has been leached out, and the approximate southwest limit of complete leaching is believed to extend across Hell Canyon near the SW corner, sec. 29, T. 5 S., R. 2 E. All the minor structures are southwest of the area of complete leaching. The thrust faults and minor folds in the Minnekahta Limestone also occur where the Minnekahta overlies the leached area, and they probably formed before the leaching of an hydrite took place. The writer believes that the only minor structures described that could be related to solution of underlying rock are the long southwest-plunging synclines in the Minnekahta Limestone and the arcuate syncline in the Spearfish Formation. The long synclines could be the reflection of subsidence directly over elongate solution chambers. This possibility is rejected, however, because breccia pipes were not observed along the trends of the synclines and because the parallelism between the trend of the synclines and the sharp anticline in the Minnekahta Limestone (which could not be due to subsidence) suggests a common origin.

The conversion of anhydrite to gypsum could result in expansion of the rocks and produce the minor deformational features. In USGS 2, Pass Creek core test (pl. 21), the sulfate beds of the Opeche Formation, which were penetrated at a depth of about 150 feet, are gypsum. However, underlying beds of sulfate in the Minnelusa Formation, are anhydrite. Where the Minnekahta Limestone is exposed on the surface and where stream valleys do not cut into the Minnelusa Formation, sulfate beds in the Minnelusa are probably still anhydrite; consequently the sulfate beds must be dismissed from the present considerations. The writer does not believe that the expansion of the two 5-foot beds of sulfate in the Opeche Formation, which are 60 feet below the Minnekahta or that expansion of sulfate beds in the Spearfish, which are 100 feet above the Minnekahta, could have had any appreciable deforming effect upon this limestone unit. Those structures in which the gypsum beds themselves have been deformed are the ones most likely to have been produced by recrystallization, if this mechanism is effective. It does not seem possible that the intense folding and segmentation of thin gypsum beds, such as that shown in figure 56, could be the result of expansion of anhydrite. The large pull-apart structure shown in figure 55 implies the extension of the gypsum bed rather than the compression of it; the relation of this extension to volume increase during recrystallization is extremely difficult to visualize.

Many examples of plastic flowage of salt and gypsum have been described in the literature, and De Sitter (1956, p. 79) lists gypsum as one of the most incompetent rock types. Thus the structures in the gypsum beds may be due to plastic flowage caused by differential compaction or incipient folding. It is probable that these beds were converted to gypsum only after erosion had removed all but a few hundred feet of the overlying strata, and it is also probable that the structures shown by these beds were developed during uplift of the Black Hills in Late Cretaceous. The writer's impression is that when the beds were deformed, the sulfate units were more competent than the enclosing siltstone units. The sulfate beds fractured, and they were segmented and separated in much the same fashion as thin competent units caught up in a mass of plastically deforming shale.

The uniform preferred orientation of the small thrust faults and minor folds in the Minnekahta Limestone indicates that this unit was deformed by compressive stress directed parallel to the bedding in a northeast-southwest direction. The compressive stress was probably the small component of the weight of the overlying column of rocks that, following the tilting of the rocks away from the center of the Black Hills, acted parallel to the dip. As the angle of tilt increased, the component of gravity probably became great enough to cause shortening of the rocks parallel to the direction of the dip.

This line of reasoning indicates that the siltstone in the Opeche and lower part of the Spearfish were particularly incompetent parts of the stratigraphic section at the time of uplift of the Black Hills, and that the overlying rocks may have slid relatively more downdip than the underlying units. Within the incompetent units, minor structures were produced as a result of the sliding. The southwest-trending anticlines and synclines in the Minnekahta Limestone are nearly parallel to the postulated direction of sliding. These folds may have been produced as a result of adjacent masses of rock sliding in slightly different directions. The pull-apart structure in the G_3 gypsum bed could also have been produced by adjacent rock sliding that tended to stretch the bed. The many small folds in the thin gypsum beds and the dolomite breccias would have formed as a result of the plastic deformation of the incompetent zone during sliding. The angle of dip (sliding gradient) in the Jewel Cave SW quadrangle is about 2°; it becomes somewhat steeper to the southwest.

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Seismic crews want to test up to 46,000 acres northwest of Provo for oil and

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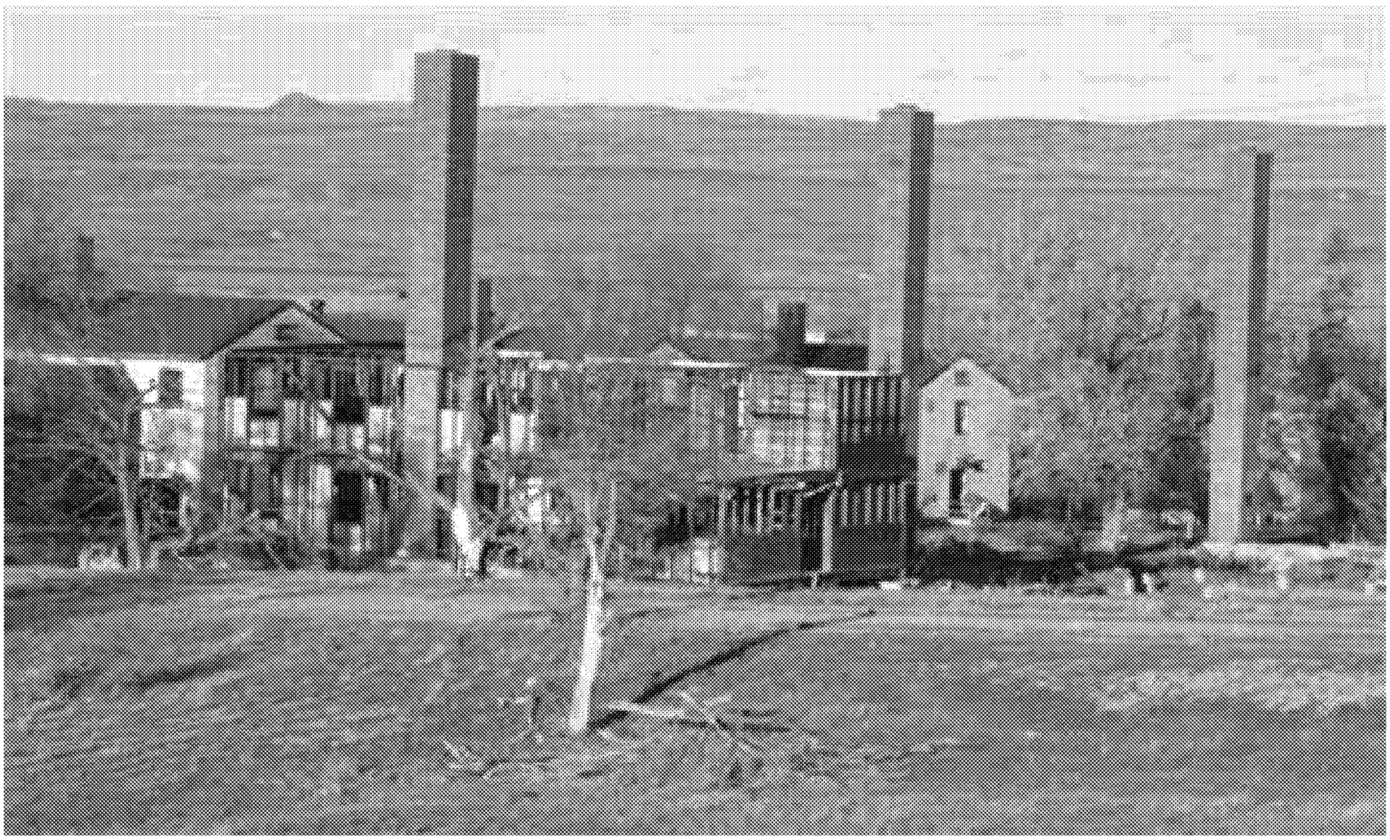
FEATURED

Seismic crews want to test up to 46,000 acres northwest of Provo for oil and gas deposit

Black Hills Army Depot chemical weapons disposal methods could prove deadly in this effort, say residents

John D. Taylor Hot Springs Star
May 14, 2017



This file photo shows the former housing area of the Black Hills Army Depot near of Edgemont.

Associated Press

Seismic crews want to test up to 46,000 acres northwest of Provo for oil and

John D. Taylor Hot Springs Star

HOT SPRINGS | A seismic testing company plans to start looking for underground oil and natural gas deposits on up to 46,000 acres of private and public land in southwestern Fall River County.

The area to be tested, between Provo and Edgemont at the edge of the Southern Black Hills, includes the former Black Hills Army Depot ground, which is now private land, and part of the Buffalo Gap National Grasslands acreage.

That region of southwestern South Dakota has a long history of energy production, energy waste storage and munitions stockpiling. Uranium was mined there in the 20th century, and a proposal is now under consideration to implement an in situ system to mine for uranium via thousands of small wells drilled into the earth. The area is also home to a former Army munitions depot, which some residents fear could leach chemicals or set off decommissioned weaponry if disturbed by the seismic testing.

At a meeting of the Fall River County Commission on May 2, some county residents — including one resident who lives quite near the area to be tested — were extremely concerned about what could happen if the remains of the ammunition, bombs, rockets and a wide array of chemical weapons that the Black Hills Army Depot handled during the 22 years of its existence and buried in vaults and trenches are disturbed by the testing.

Seismic testing

According to Mike McNeil of the U.S. Forest Service Hot Springs office, there will be up to 23,000 acres of private land and an equal amount of National Grasslands acreage that could be tested.

McNeil said a private company, employed by landowners in the area, is using seismic surveys to look for oil and gas deposits.

Seismic testing involves a large metal plate that is pushed down on top of the earth, through which high-frequency vibrations, called seismic waves, are sent. The waves are created by either a dynamite blast or a specialized air gun. The waves bounce back, or reflect, in the rock strata, and are recorded by receivers known as geophones. Oil and gas geologists can read the seismographs generated by the testing unit to determine if there are pockets of oil or natural gas below.

The bulk of the testing would take place in the Coffee Flats area, he said. However, other areas around Provo are also involved.

The company doing the testing is obligated to get permission only from private mineral rights owners (not necessarily landowners) and an internal permission from the Forest Service and the Bureau of Land Management, the federal agency that controls the mineral rights on the grassland areas to be tested, said Kelly Stover, also with the Hot Springs Forest Service office.

Seismic crews want to test up to 46,000 acres northwest of Provo for oil and

The conditions the Forest Service has put on the testing are:

• No seismic testing prior to Aug. 1, to protect raptors and sharp-tailed grouse, currently nesting on the grasslands.

• Roads of all types, BLM, USFS, county and private, must be returned to their previous condition following testing. Seismic testing vehicles are especially heavy.

• No travel on wet roads.

• Local residents must be contacted prior to testing.

Fall River County commissioners and audience members raised a number of questions about this effort.

They wanted to know how cattle could be affected by the testing. Stover said there would be no harassment of livestock.

Questions were also asked about the specifics of where the seismic testing would be done. McNeil said it would not occur east of Provo and not on the BHAD "Burning Grounds."

Seismic crews want to test up to 46,000 acres northwest of Provo for oil and

Chemical weapon worries

A more significant worry was raised by Edgemont rancher Susan Henderson and Provo rancher Cindy Brunson, who lives practically on top of the former BHAD.

"This is a disaster of massive proportion," warned Henderson.

For 10 years, roughly from 1991-2001, Henderson served as chairwoman of the Restoration Advisory Board, a citizens advisory board that provided a liaison between the U.S. Army and local people for the potential cleanup of the Army depot site. Congress mandated a cleanup of the depot, and then-U.S. Sen. Tom Daschle recommended Henderson for the board. This project had a $5 billion budget, Henderson told the commissioners.

The Army depot had served the nation as a munitions storage and decommissioning facility beginning in 1942.

Seismic crews want to test up to 46,000 acres northwest of Provo for oil and

Initially operated by the U.S. Army Ordinance Corps to meet a World War II increased demand for ordnance, the depot was chosen for its remoteness, with nearly all of the facility's civilian workforce living in federal housing in Igloo, once a booming community but now an abandoned town.

The depot was also used for storing and testing chemical weapons, including some highly toxic gases. They included:

• Sarin, or GB gas, a colorless, odorless liquid used as a weapon due to its extreme potency as a nerve agent. Sarin in its purest form is estimated to be 26 times more deadly than cyanide and 543 times more lethal than the chlorine gas used during World War I. Sarin exposure causes difficulty breathing, loss of bodily functions, followed by twitching and jerking. Ultimately the victim suffocates in a series of convulsive spasms. Sarin was outlawed in 1997 by arms control treaties, but most nations that produced it retained stockpiles of the weapons used to deliver it, as witnessed by what has happened in Syria recently.

Seismic crews want to test up to 46,000 acres northwest of Provo for oil and

• Mustard gas (sulfur mustard) forms chemical burns on the skin, eyes and lungs. It was first used as a weapon during World War I by the Germans when it was shot over troops via artillery shells. Mustard gas was also outlawed by arms control treaties.

• Phosgene gas also gained infamy as a chemical weapon during WWI. A suffocating gas, it was responsible for nearly 85 percent of the 100,000 deaths caused by chemical weapons in that war.

• Lewisite, another blistering agent developed during WWI, but not used then, was known during 1920s experiments as the "Dew of Death." The U.S. produced about 20,000 tons of lewisite, using it as an antifreeze for mustard gas or to penetrate protective clothing in special circumstances. It was replaced by a mustard gas variant during the 1950s and declared obsolete.

• VX, short for "venomous agent X" gas, is an extremely toxic nerve gas developed for
Seismic crews want to test up to 46,000 acres northwest of Provo for oil and
military use after pesticide research discovered the toxicity of organophosphates such as malathion and parathion. VX stays around, doing damage in environments where it is used.

• Other nerve gases were also created and handled at the Army depot during WWII, including Tabun, a German product, Toban and the very deadly Soman, which can kill in two minutes.

The Army depot was closed on June 30, 1967.

However, the citizens advisory board quickly learned that the depot had some major disposal problems for munitions.

“Igloo was designed to take in WWII weapons that were difficult to manage,” Henderson told the commissioners. Disposal was done in three basic ways: Stored in underground caverns; left in 200 miles of trenches dug at various locations around the base; or in 20-square-foot cement bunkers.

The trenches were used to bury weapons, including chemical agents in containers, bombs and rockets around the depot, Henderson said. That included M55 rockets.

A 1990s congressional study showed that thousands of the rockets were filled with chemical agents. Today, some 50 to 75 years after they were buried, a Sandia Labs study showed these rockets are destabilizing and could "auto ignite."

Seismic crews want to test up to 46,000 acres northwest of Provo for oil and

Also, when the temperature of the rocket rises above 55 degrees, it can ignite. There have been multiple "blow-ups" of these rockets in other areas where the rockets were stored, Henderson said, sharing her worry that seismic testing could set off a chain reaction of rockets in trenches.

Chemical gas-filled rockets and bombs were also buried in bunkers, she said.

"There were hundreds of thousands of tons of chemical warfare agents stored or buried underground, 368,000 tons of Sarin alone," she said, "along with GB, VX, mustard gas, terrible Nazi stuff and secret stuff that no one knows about."

Henderson believes that the aim of the military following World War II was to tap into Wind Cave's vast underground caverns, which recent cavern mapping shows extend for many miles, possibly even to the edges of the Army depot. The caverns, it was thought, would stay cool and make it easier to control stockpiled ordnance.

She also said the chemicals and gasses in the weapons are percolating down into the water table.

“I don’t know what will happen when seismic crews go shaking ground around this,” Henderson said. “This has me scared to death. Because time has passed all those who worked there are dead or gone, and people don’t remember what’s in there anymore.”

Both Henderson and Brunson talked about a sheep rancher, Georgia LaBarre, who lost 1,200 sheep on Army depot land in the early 1990s when they were grazing. They both surmised it was due to improperly disposed ordnance. Henderson said she saw some of those sheep with grass in their mouths that had convulsed so hard their backs were broken, but also that they did not bloat and flies would not land on them. Four of those animals were taken to the state veterinarian, who saw no sheep disease but suspected some horrible chemical warfare agent in their deaths, Henderson said.

"The bottom line here is that doing this (seismic testing) is insane," Henderson said. "It's extremely scary, it's unconscionable."

Seismic crews want to test up to 46,000 acres northwest of Provo for oil and

Brunson told of losing grazing cattle to mysterious causes on depot lands.

"We need energy," Brunson said, "but nobody should go there (to the Army depot site). I border on the west side of the burn pit and can see across the fence, where work is being done. I'd advise these people to stay away."

A 300-page Army Corps of Engineers commissioned report from 1992 backs up most of Henderson and Brunson's statements.

Also, Stover said that archeological and paleontological studies are being done.

Only Forest Service approval is needed for a short-term exploration effort like this, McNeil and Stover told the commissioners. The federal Bureau of Land Management and private landowners own the underground mineral rights of the lands in the project, while the Forest Service and private landowners hold the above-ground land rights.

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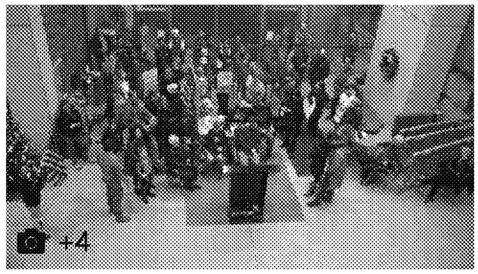

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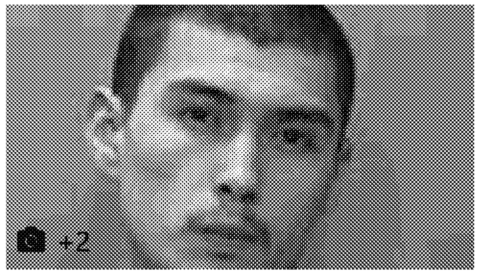

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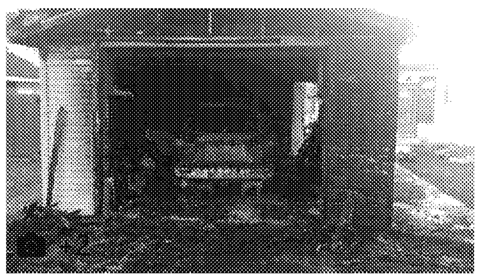

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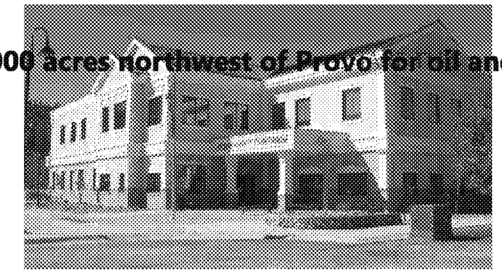

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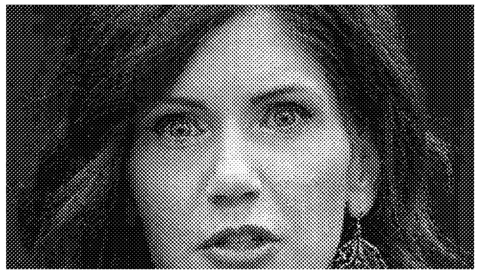

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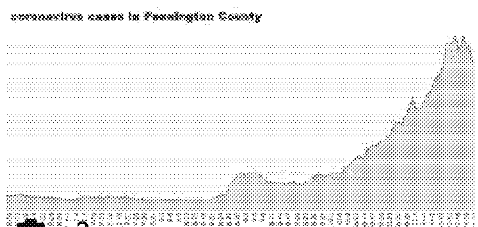

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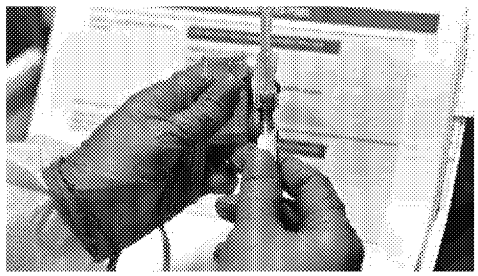

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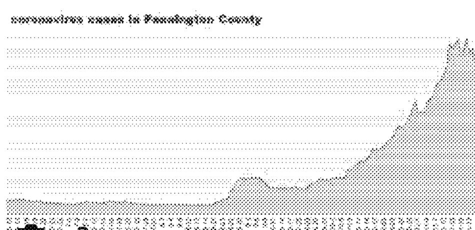

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Your Two Cents for Dec. 1

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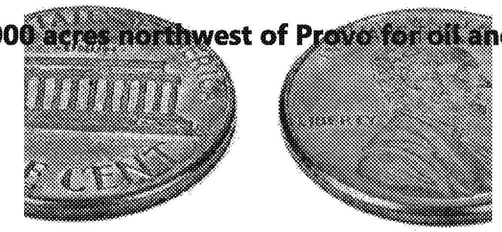

Published: 25 April 2017

Global aquifers dominated by fossil groundwaters but wells vulnerable to modern contamination

Scott Jasechko, Debra Perrone, Kevin M. Befus, M. Bayani Cardenas, Grant Ferguson, Tom Gleeson, Elco Luijendijk, Jeffrey J. McDonnell, Richard G. Taylor, Yoshihide Wada & James W. Kirchner

Nature Geoscience **10**, 425–429(2017)

Abstract

The vulnerability of groundwater to contamination is closely related to its age. Groundwaters that infiltrated prior to the Holocene have been documented in many aquifers and are widely assumed to be unaffected by modern contamination. However, the global prevalence of these 'fossil' groundwaters and their vulnerability to modern-era pollutants remain unclear. Here we analyse groundwater carbon isotope data (^{12}C, ^{13}C, ^{14}C) from 6,455 wells around the globe. We show that fossil groundwaters comprise a large share (42–85%) of total aquifer storage in the upper 1 km of the crust, and the majority of waters pumped from wells deeper than 250 m. However, half of the wells in our study that are dominated by fossil groundwater also contain detectable levels of tritium, indicating the presence of much younger, decadal-age waters and suggesting that contemporary contaminants may be able to reach deep wells that tap fossil aquifers. We conclude that water quality risk should be considered along with sustainable use when managing fossil groundwater resources.

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S.J. and J.W.K. analysed the compiled groundwater isotope data and wrote initial drafts of the manuscript. S.J. and D.P. analysed the compiled groundwater well construction data. All authors discussed results and edited the manuscript.

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Ethics declarations

Competing interests

The authors declare no competing financial interests.

Supplementary information

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